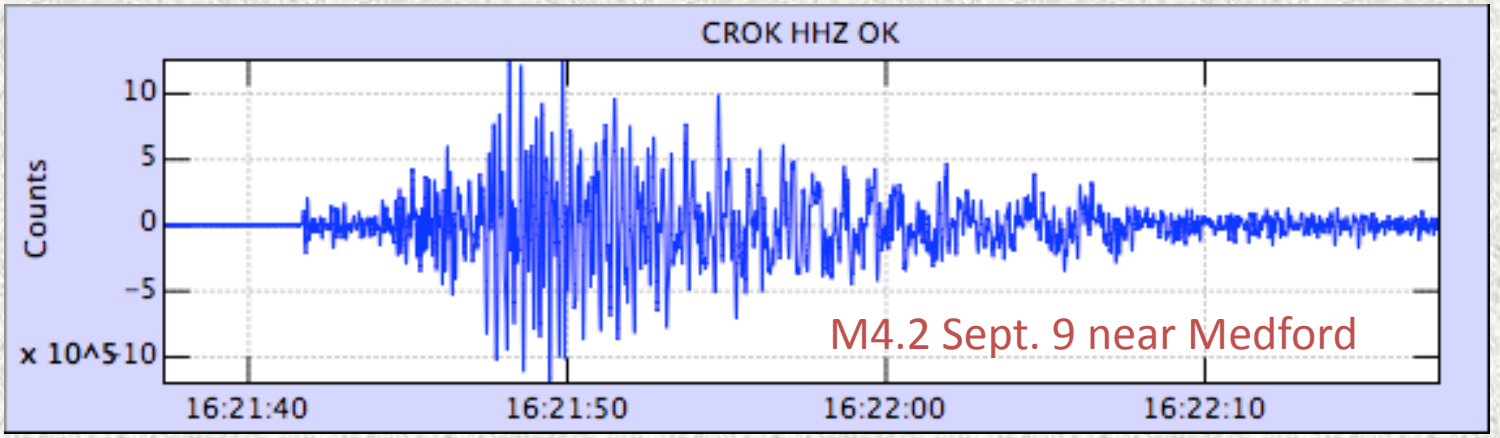
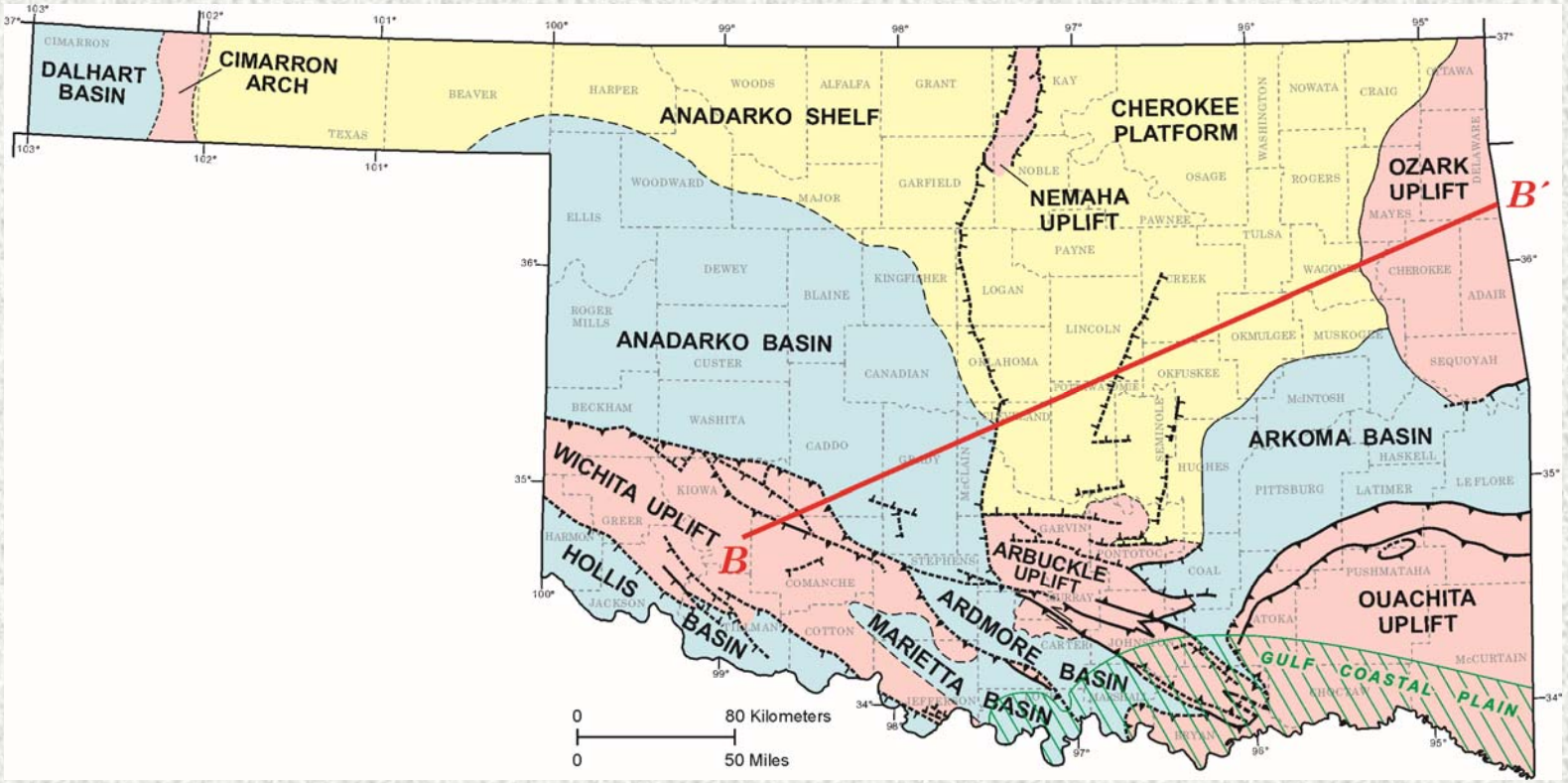
MEWBOURNE
COLLEGE OF EARTH & ENERGY
THE UNIVERSITY OF OKLAHOMA

The Oklahoma Geological Survey is a state agency for research and public service located on the Norman Campus of the University of Oklahoma and affiliated with the OU College of Earth and Energy. The Survey is chartered in the Oklahoma Constitution and is charged with investigating the state's land, water, mineral, and energy resources and disseminating the results of those investigations to promote the wise use of Oklahoma's natural resources consistent with sound environmental practices.

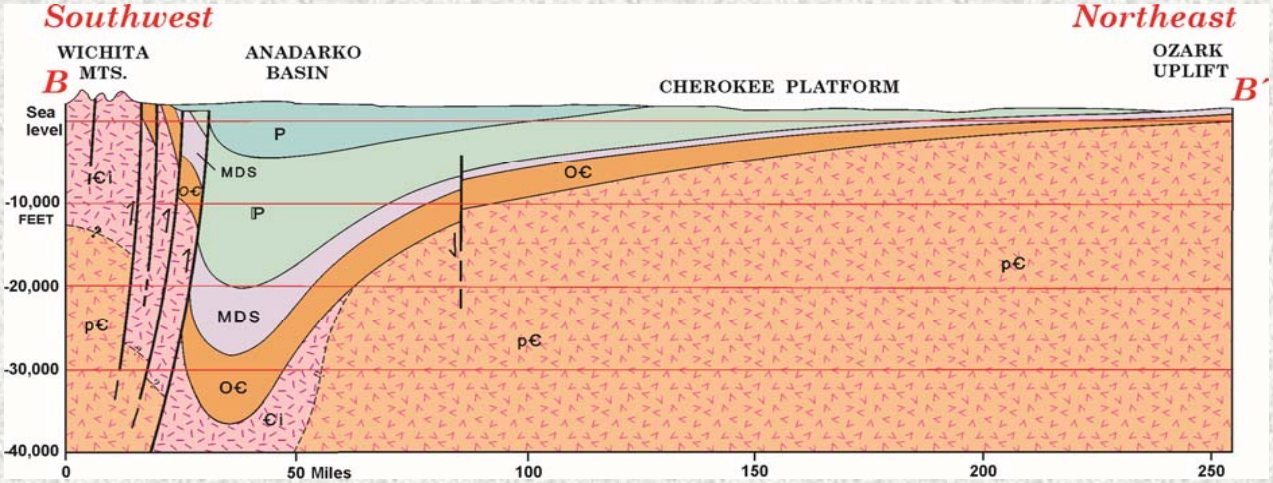


OGS Seismic Monitoring Program

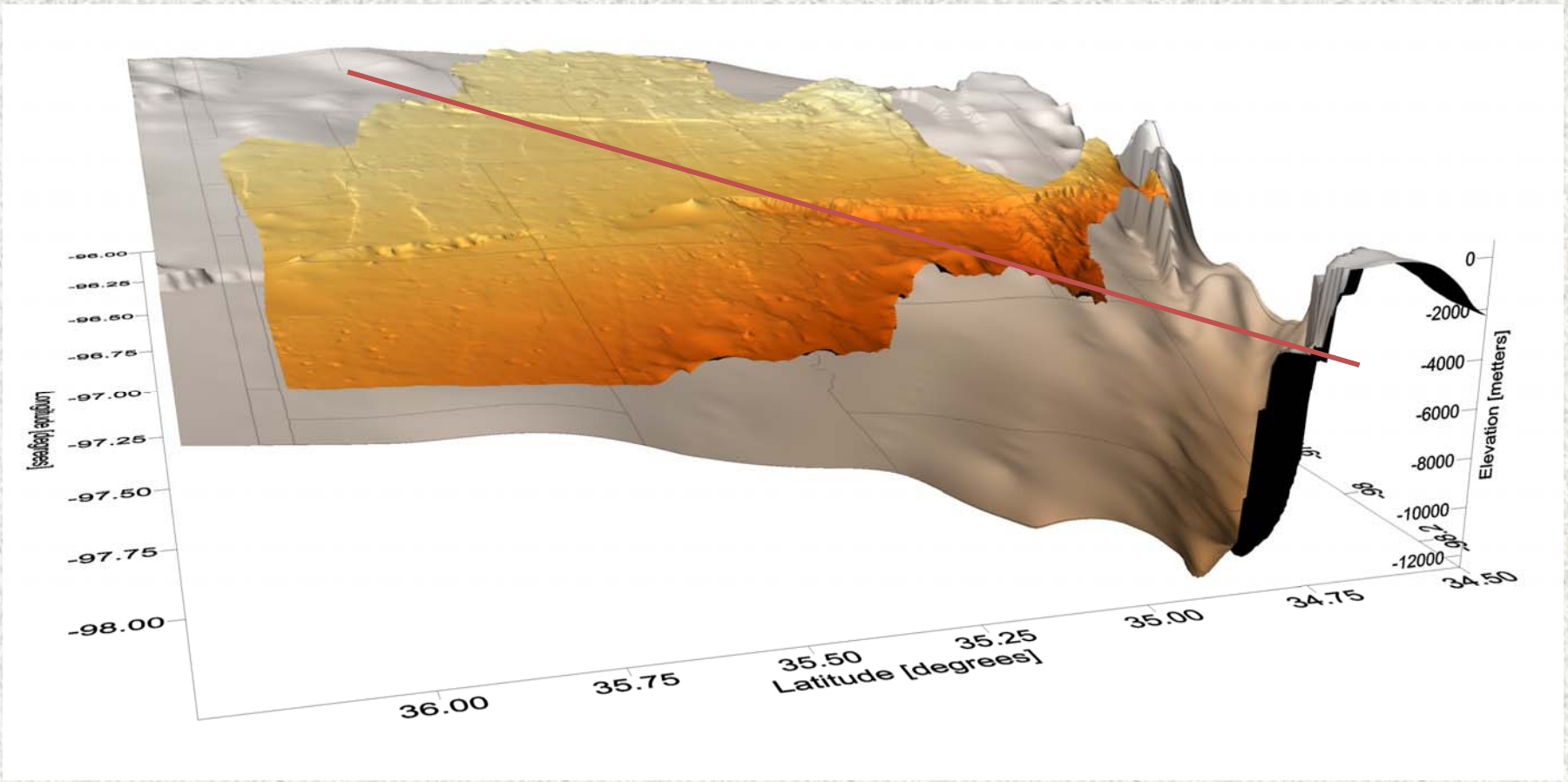
- The OGS operates a network of seismic stations that began operating in 1978. A station was operating near Tulsa in 1962.
- All of our raw data is collected and archived. It is also shared in real-time with the USGS or vice-versa and then archived at an international data management center such that it is publicly available to all researchers.
- Seismologists and trained analysts process earthquake data manually. We do not have the computer automatically calculate an earthquake location, time, and magnitude.
- Our website provides earthquake catalogs, recent earthquake lists and maps as well as our research results and educational materials. These resources are provided to the Corporation Commission, other researchers and the general public.



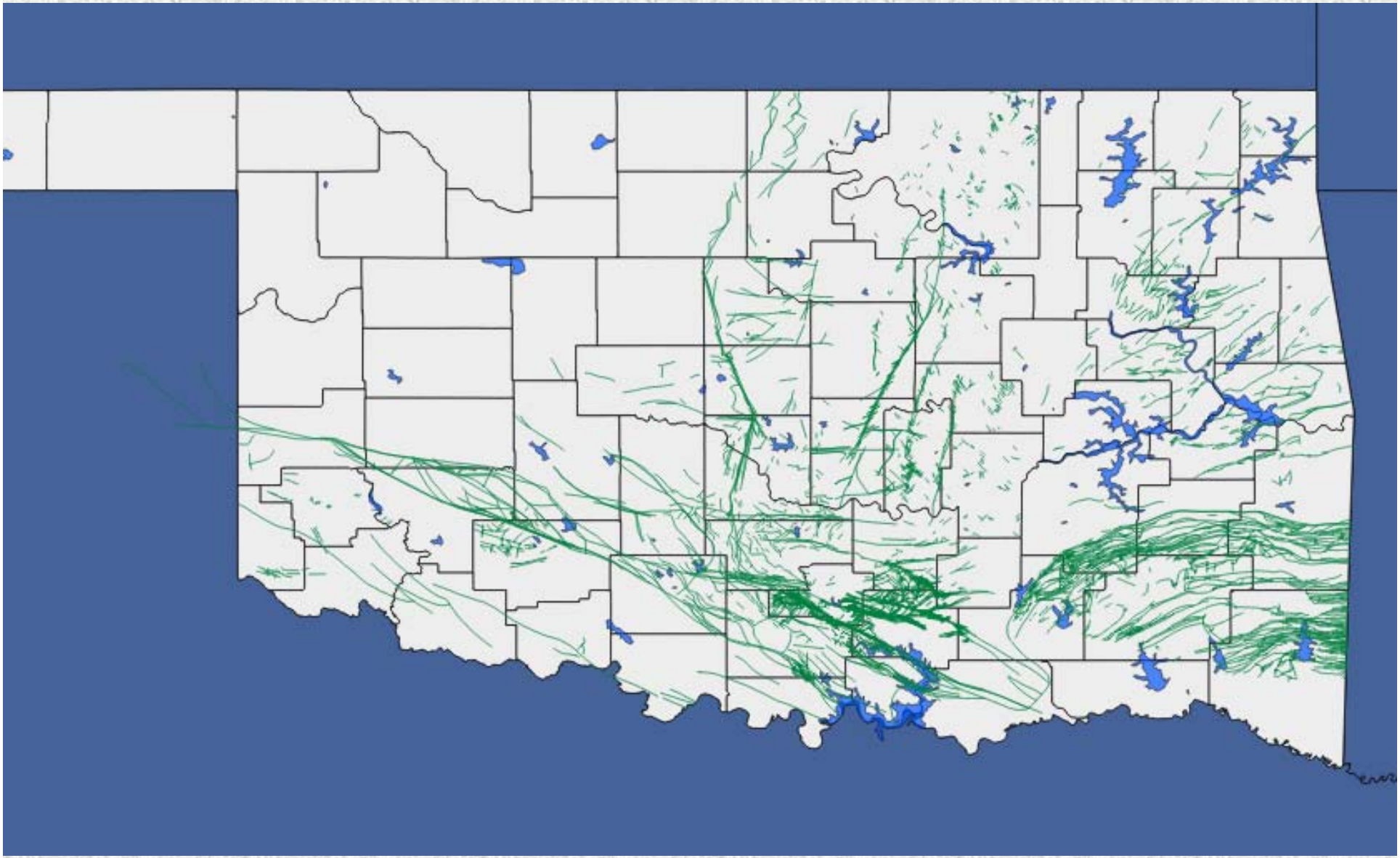
P	Permian
ℙ	Pennsylvanian
MDS	Mississippian, Devonian, and Silurian
O€	Ordovician and Cambrian (sedimentary rocks)
€i	Cambrian (igneous and metamorphic rocks)
p€	Precambrian



A perspective view

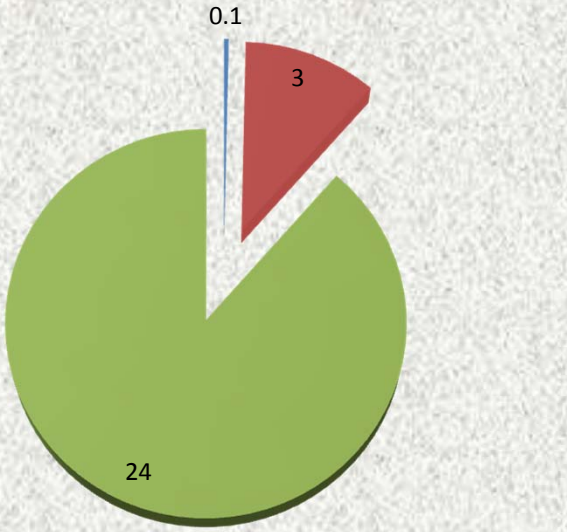


Mapped Faults in Oklahoma

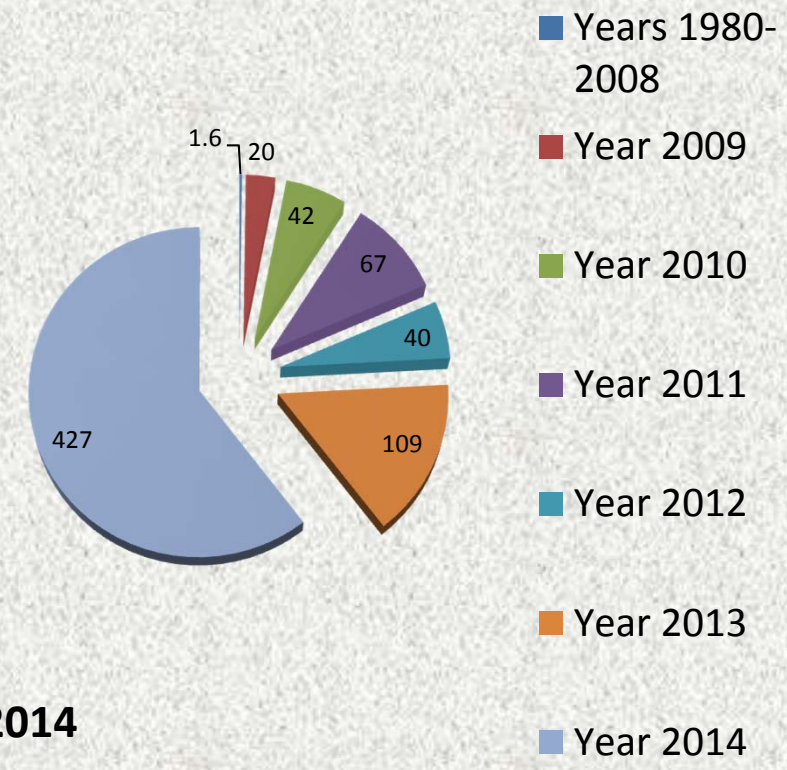


Oklahoma's Increase in Earthquakes
Earthquake rates per year

Magnitude 4 or Greater Earthquakes

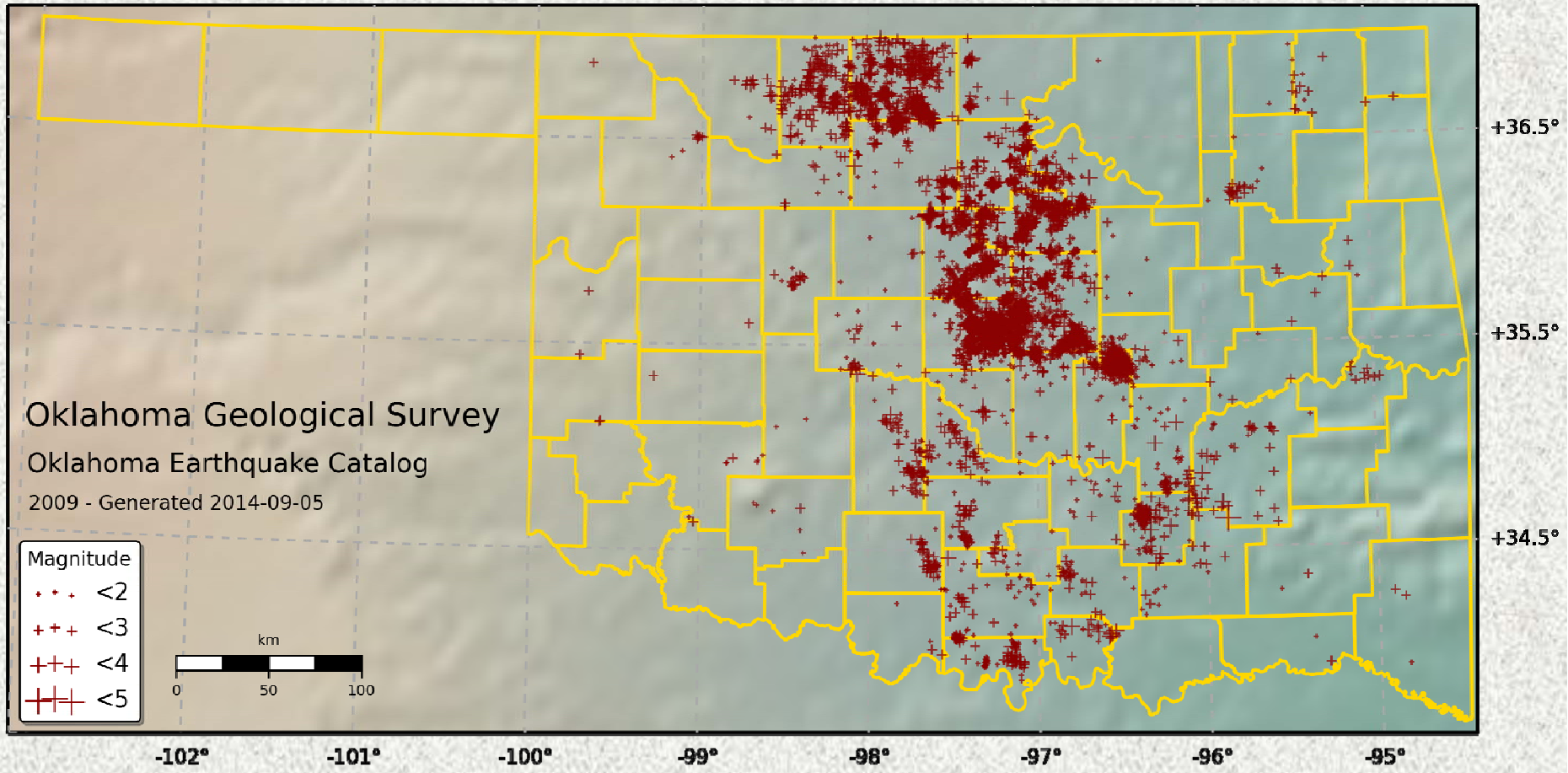


Magnitude 3 or Greater Earthquakes



Updated Oct. 20, 2014

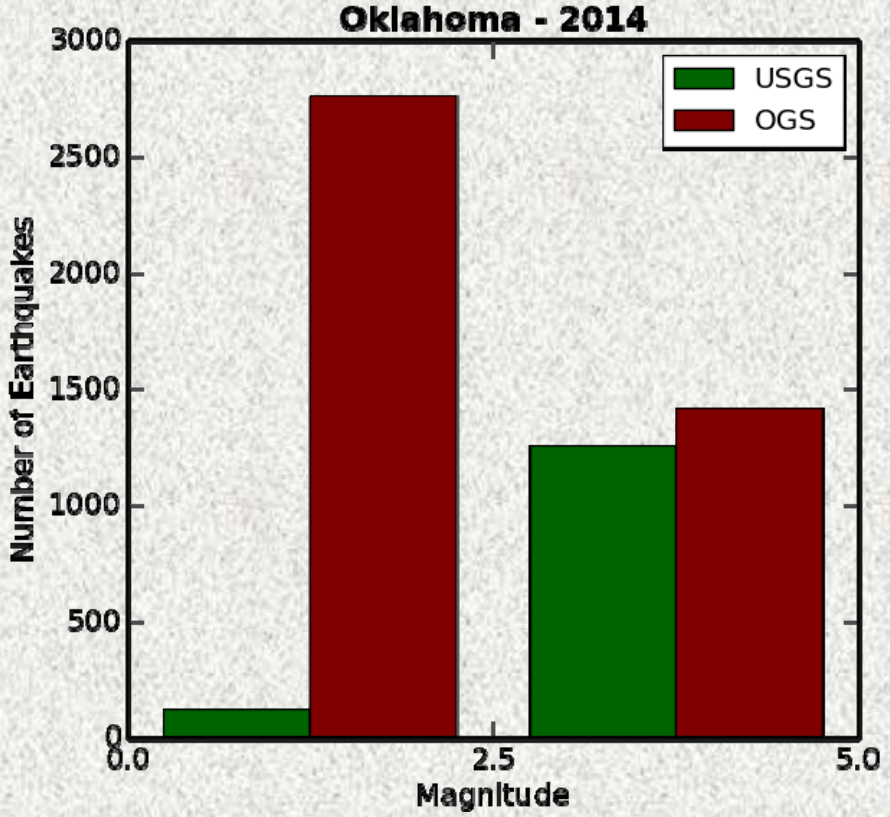
Earthquakes 2009-2014



Increase in earthquakes is occurring over about 10,000 square miles

OGS Catalogs Many Earthquakes in Oklahoma (2014)

- 4179 – OGS number Earthquakes
- 1372 – USGS number Earthquakes
- We are aware of many more earthquakes that have occurred in 2014, but have not processed all of them.
- Complete to about
  - OGS M2.3
  - USGS M3.0

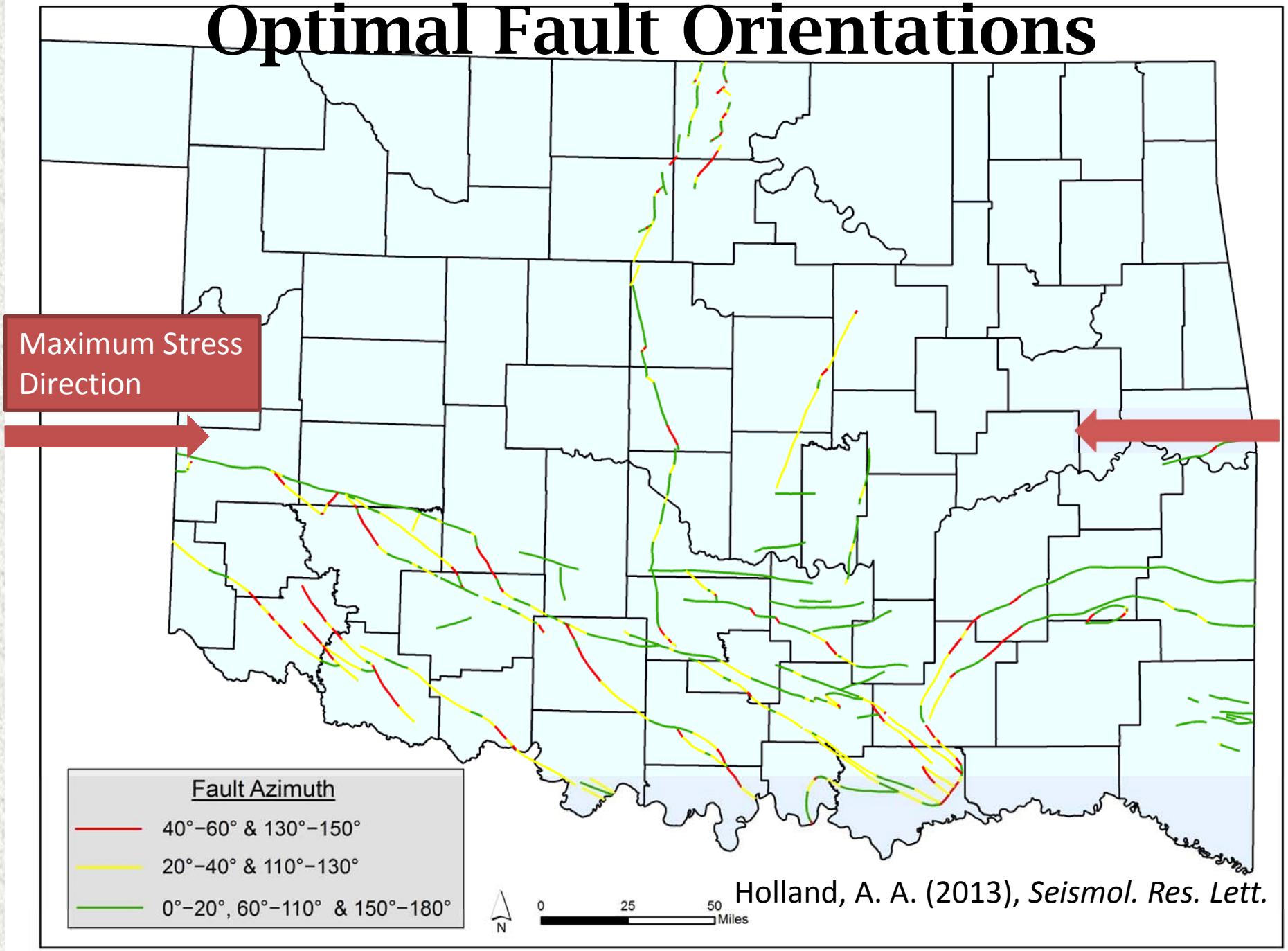


Updated Oct. 27, 2014

What we have learned so far

- Because of our increased seismic monitoring capabilities, we have learned a variety of things about the earthquakes that are occurring. All of our research products are available on our Earthquake Research webpage and in different publications.
  - http://www.okgeosurvey1.gov/pages/research.php
  - The earthquake hazard has increased as a result of the increase in earthquakes.
  - Determination of earthquake location parameters has improved dramatically.
  - Earthquakes are occurring on faults that are properly oriented to have earthquakes given the natural regional stresses or forces, with the exception of a few areas of the state.

Optimal Fault Orientations



Holland, A. A. (2013), *Seismol. Res. Lett.*

Potential for Induced Seismicity

- Scientists understand the basic physics and processes of earthquakes triggered by fluid injection.
  - No different than natural earthquakes, which cannot be predicted. Much remains to be learned about the physical states and properties deep within the Earth.
- We have two documented cases of earthquakes likely triggered by hydraulic fracturing with earthquakes large enough to be felt by local residents, but none were large enough to cause damage. These cases represent a very small percentage of the thousands of wells that have been hydraulically fractured over the past 5 years.
- There is general agreement amongst scientists examining induced seismicity that earthquakes triggered by disposal wells pose a greater risk than earthquakes triggered by hydraulic fracturing.
- Identifying potential cases of induced seismicity associated with disposal wells is more challenging.
  - This is due to the fact that these wells operate over significant time periods and partly because there are significant numbers of disposal wells operating within the state of Oklahoma.
  - Primarily these wells dispose naturally occurring “salt-water” (SWD) that is removed from the ground by the production of oil and gas. This is called “produced water”.

Potential for Induced Seismicity

- We have identified a potential case of earthquakes triggered by a salt water disposal well (SWD) in Love county, and we have documented this sequence.
- The Jones earthquake swarm has been recognized as potentially triggered by SWD by myself in a publication released a year ago, because the earthquakes are statistically different, and by another study published earlier this summer. However, a great number of questions remain regarding this earthquake swarm.
- It has also been suggested that the Prague earthquake sequence including the M5.7 in November 2011 was also triggered by SWD in the area. While we cannot rule out the possibility of these earthquakes having been triggered by SWD. The earthquakes also appear consistent with a naturally occurring sequence. Our observations are presented in an OGS statement about the cause of the 2011 Prague sequence that is available on our website and remain relevant today. This sequence continues to be a significant portion of ours and national research efforts, as the EQ represents the largest earthquake in Oklahoma since 1952.

OGS Response to Increase in Earthquakes

- We have hired a second research seismologist and also have a geohydrologist to help address these issues.
- We held a workshop regarding best-practices regarding fluid injection as it relates to the potential for triggered seismicity in July of 2013. A broad range of stakeholders from state and federal regulators to industry and environmental groups were in attendance.
- We have been contributing to research occurring nationally on issues of induced seismicity relating to oil and gas as part of the USGS Powell Center Workgroup on Induced Seismicity and through direct contact with other researchers.

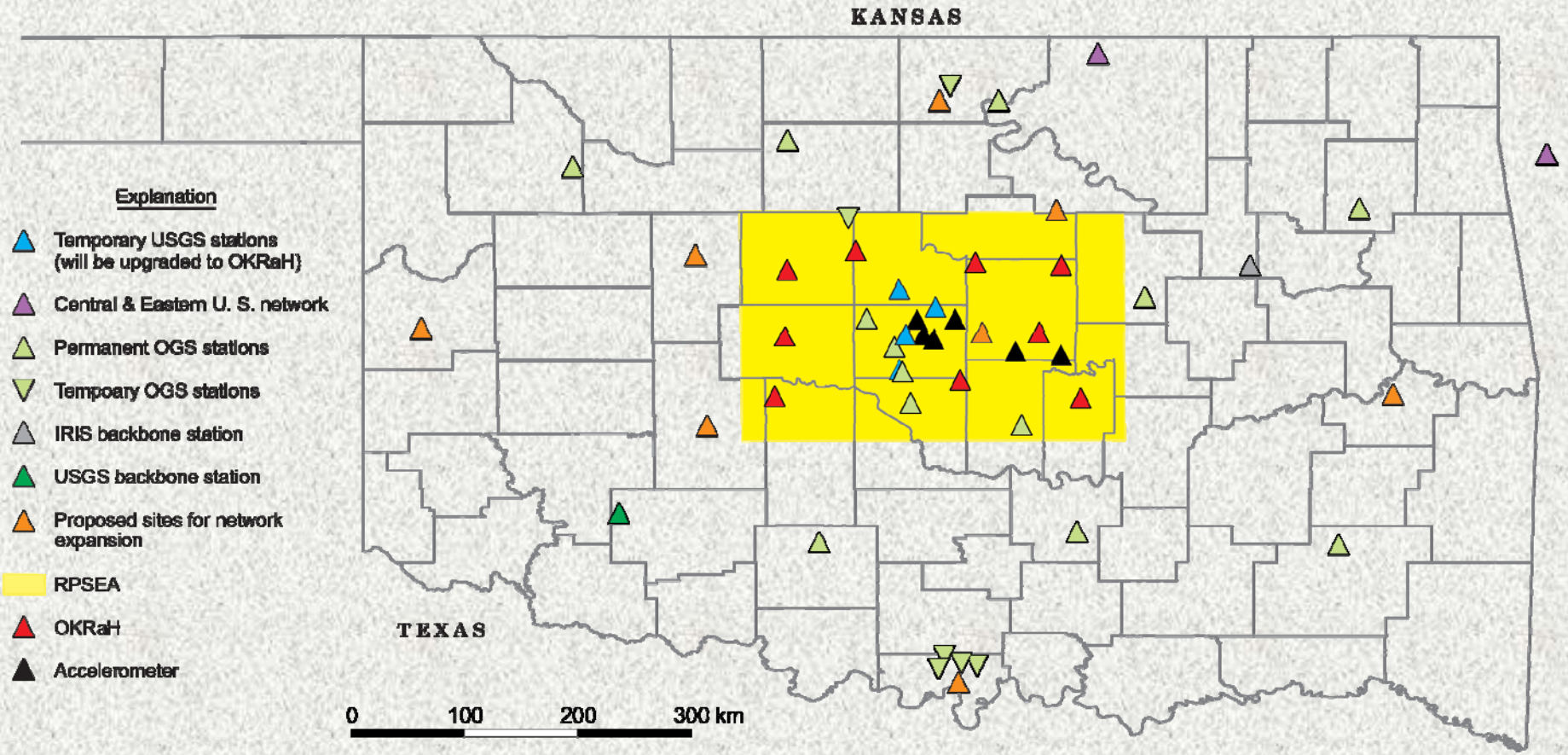
OGS Response to Increase in Earthquakes

- The OGS is participating in an IOGCC/GWPC initiative for states to collaborate on and address concerns and practices regarding induced seismicity.
- We have a project working with the OIPA to build a better fault database and catalog of the known faults within Oklahoma.
- Co-hosting a workshop with the USGS on Induced Seismicity and Seismic Hazards for the National Seismic Hazard Map (Nov. 18, 2014).
- We will continue to publish about potential cases of induced seismicity and results of our research. The results of our research are then tools that can be used by all stakeholders.

OGS Seismic Monitoring Response to Increase in Earthquakes

- Operating 16 temporary stations within Oklahoma (about to be 18)
- Adding 8 more permanent stations to the OGS regional network. (Funding provided from the OCC and Secretary of Energy and Environments office)
- Co-operating 5 USGS temporary stations provided installation and batteries
- Operating 6 USGS accelerometer stations
- Supporting more than three times as many stations than in 2009

RPSEA 2 Year Grant



- We have a 2-year collaborative grant with researchers at OU to more carefully study with geophysical and geological characterization as well as reservoir and geomechanical modeling.